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IMAGE REJECTION MIXING IN WIDEBAND APPLICATIONS

BACKGROUND

This invention generally relates to wideband communication systems. In particular, the invention relates to image suppression in received wideband communications.

Wideband communication systems, such as television and radio communication systems, use a wide frequency spectrum to communicate information. Typically, the wide spectrum is divided into a group of assigned radio frequencies for carrying the information.

In a heterodyne receiver, the received signal is amplified by a radio frequency (RF) amplifier and mixed with an adjustable local oscillator (LO) signal to produce intermediate frequency (IF) signal. One problem with mixer circuits is the generation of image frequency signals.

When two signals are mixed, signal components are produced at the sum and difference of the two signals, and their harmonics. Equation 1 illustrates the potential signal components where F_{LO} is a local oscillator frequency being mixed with a radio frequency, F_{RF} and m and n are integers or zero.

$$\pm m F_{RF} \pm n F_{LO} \qquad \text{Equation 1}$$

Since input circuits typically have limited selectivity in the mixing process, undesired interference may create harmful products, as illustrated by Equation 2. F_I is an undesired interference frequency and m, n and p are an integer or zero.

$$\pm m F_{RF} \pm n F_{LO} \pm p F_I \qquad \text{Equation 2}$$

For example, when an intermediate frequency signal, F_{RF}, is mixed with a local oscillator, F_{LO}, the result will produce signals at two frequencies, $F_{LO} + F_{RF}$ and $F_{LO} - F_{RF}$. One of the two signals is the desired frequency and the other is at an undesired frequency. Additionally, based on the quality of the mixers, undesirable harmonics, such as $F_{LO} + 2F_{RF}$, could also be produced. In a wideband communication system utilizing multiple frequencies, the frequencies that these undesired signals fall upon may be the same frequency used for another information signal. As a result, the undesired signal produces an image on the desired information signal at that frequency.

One approach to removing the image signal from the desired signal is by filtering. Typically, filtering only reduces the magnitude of the image signal by less than 30 decibels (dB). In some applications, a 30 dB attenuation is not sufficient.

Ins A1 a17 ~~Another approach is to use an image rejection mixer 10, as illustrated in Figure 1. A received radio frequency signal is input into the image rejection mixer 10. The received signal is input to an in-phase mixer 14 and a quadrature phase mixer 12. A local oscillator (LO) 11 generates a carrier signal. The carrier signal is input into the quadrature phase mixer 12 to produce a demodulated quadrature phase signal and into a 90 degree phase shift device 16, such as a RC–CR circuit, to produce an in-phase carrier. The in-phase carrier is input into the in-phase mixer 12 to produce a demodulated in-phase signal. The demodulated quadrature phase signal is subsequently delayed by a 90 degree phase shift device 22. An adder 20 combines the phase delayed quadrature phase signal to the in-phase signal to produce the desired signal. Typically, the image signal will be out of phase with the desired signal. As a result, the combining cancels the image signal leaving only the desired signal.~~

To illustrate, W_{RF} is the frequency of the received signal and W_{LO} is the frequency at the local oscillator. The image rejection mixer 10 processes the desired signal as follows. I(t) is the demodulated in-phase signal. Q(t) is the demodulated quadrature phase signal. Q'(t) is the phase delayed quadrature phase signal. O(t) is the subtracted signal.

$$I(t) = \cos(W_{RF}t) * \cos(W_{LO}t) =$$

$$= \tfrac{1}{2}[\cos(W_{RF} - W_{LO})t + \cos(W_{RF} + W_{LO})t], \text{ where } W_{RF} - W_{LO} > 0$$

Equation 3

The $\cos(W_{RF} + W_{LO})t$ is removed by low-pass filtering.

$$Q(t) = \cos(W_{RF}t) * \cos(W_{LO}t - \pi/2) =$$

$$= \tfrac{1}{2}\cos[(W_{RF} - W_{LO})t + \pi/2] = -\tfrac{1}{2}\sin(W_{RF} - W_{LO})t$$

Equation 4

$$Q'(t) = -\tfrac{1}{2}\sin[(W_{RF} - W_{LO})t - \pi/2] = \tfrac{1}{2}\cos(W_{RF} - W_{LO})t$$

Equation 5

$$O(t) = I(t) + Q'(t) = \cos(W_{RF} - W_{LO})t$$ Equation 6

The image rejection mixer 10 processes the image signal which is inverted with respect to the desired signal as follows.

$$I(t) = \tfrac{1}{2}\cos[-(W_{RF} - W_{LO})t] = \tfrac{1}{2}\cos(W_{RF} - W_{LO})t$$ Equation 7

$$Q(t) = \tfrac{1}{2}\cos[-(W_{RF} - W_{LO})t + \pi/2] = \tfrac{1}{2}\sin(W_{RF} - W_{LO})t$$ Equation 8

$$Q'(t) = \tfrac{1}{2}\sin[(W_{RF} - W_{LO})t - \pi/2] = -\tfrac{1}{2}\cos(W_{RF} - W_{LO})t$$ Equation 9

$$O(t) = I(t) + Q'(t) = \tfrac{1}{2}\cos(W_{RF} - W_{LO})t - \tfrac{1}{2}\cos(W_{RF} - W_{LO})t = 0$$

Equation 10

Accordingly, after image cancellation, the desired signal is recovered, Equation 6, and the image signal is canceled, Equation 10.

Due to variations in the tolerances of the resistors and capacitors in the phase shift device 16 and temperature variations, the phase differential between the carrier and the quadrature carrier may not be maintained at an ideal 90 degrees, degrading performance of the image mixer.

Accordingly, it is desirable to have alternate approaches for image suppression in received wideband signals.

SUMMARY

A ring oscillator produces an in-phase and quadrature phase radio frequency signal. A first mixer mixes the in-phase signal with a received signal. A second mixer mixes the quadrature phase signal with the received signal. A combiner, operatively coupled to the first and second mixers, produces an image cancelled signal.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an image rejection mixer.

Figure 2 is an image rejection mixer using a ring oscillator.

Figure 3 is a delay cell.

Figure 4 is a RC-CR circuit.

BRIEF DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Figure 2 illustrates an image rejection mixer 24 for use in a wideband communication system receiver, such as a television tuner or radio tuner. Although the image rejection mixer 24 is shown using balanced mixers 28, 30, such as a Gilbert cell, other mixers may be used. Balanced mixers are desirable due to their noise suppression quality. A received RF signal is buffered by a buffer 58 so that the RF signal as outputted by the buffer 58 is shifted to a desired level for the in-phase and quadrature mixers 30, 28. The buffered RF signal is inputted into both the in-phase and quadrature phase mixers 30, 28. A ring oscillator 32 produces an in-phase carrier which is input into the in-phase mixer 30 and a quadrature phase carrier which is input to the quadrature

phase mixer 28. The demodulated quadrature phase signal is subsequently delayed by a 90° phase delay device 38, such as an RC–CR circuit. The delayed quadrature phase signal is combined using an adder 40 to the in-phase signal to produce the desired signal with the image signal cancelled.

By using the ring oscillator 32, the in-phase and quadrature carrier are maintained at a near ideal 90 degree phase difference. Since the demodulated signals are at low frequencies, a simpler 90 degree phase shift device 38, such as an RC-CR circuit, may be used without degrading the image rejection mixer's performance. Using the ring oscillator 32, a 60 dB attenuation in the image signal is achieved.

One ring oscillator 32 for producing the in-phase and quadrature phase carrier uses four delay cells 44_1-44_4, as shown in Figure 2. Each delay cell 44_1-44_4 delays the input signal by 45 degrees. As a result, the first delay cell 44_1 produces a 45 degree phase delay. The second delay cell delays the 45 degree delayed signal by another 45 degrees, totaling 90 degrees. The output of the second delay cell 44_2 is inverted as to shift the phase by 180 degrees prior to being input into the third delay cell 44_3. The third delay cell 44_3 delays the 270 degree delayed signal by 45 degrees, totaling 315 degrees. The fourth cell 44_4 delays the output of the third cell 44_3 by 45 degrees totaling 360 degrees creating the oscillation. Although the output of the second cell 44_2 is shown as used for the in-phase carrier and the output of the fourth cell 44_4 for the quadrature phase carrier, any of the outputs or inputs separated by 90 degrees may be used.

One circuit for use as a delay cell 44_1-44_4 is shown in Figure 3 using CMOS circuitry. Six n-type MOSFETS 46_1-46_6 and two p-type MOSFETS 48_1, 48_2 are configured as shown in Figure 3. The inputs to the gates of the two bottom n type MOSFETS 46_1, 46_2 are connected in series to form the bias, control frequency, to the delay cells 44_1-44_4. The gates of the two lower n type MOSFETS 46_3, 46_6 form the input of the delay cells 44_1-44_n. The drains of those MOSFETS 46_3, 46_6, form the output. This CMOS circuit produces an output having a phase delayed by 45 degrees from the input.

A simple 90 degree phase shift device 38 may be used for the quadrature phase demodulated signal, such as a RC-CR circuit as shown in Figure 4. The demodulated

quadrature phase signal is input into the delay device 38. The input of the delay device 38 is coupled to a series connected resistor 50 and capacitor 52 connected in parallel to a series connected capacitor 54 and resistor 56. An output of 90 degrees of phase delay is produced at the nodes between the series connected resistors 50, 56 and capacitors 52, 54.

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